Phenology of the alfalfa weevil (Coleoptera: Curculionidae) in alfalfa grown for seed in southern Alberta

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ABSTRACT

An algorithm to forecast occurrence of four life-stage categories of the alfalfa weevil, *Hypera postica* (Gyllenhal), was derived from data collected in fields of seed alfalfa, *Medicago sativa* (L.) in southern Alberta. The algorithm assumes a linear developmental response to mean daily temperatures above a threshold of 10°C. Overwintering adults were active after the accumulation of 100 degree-days above 10°C (DD_{10}), and were scarce by 250-300 DD_{10}. Early larvae (instars 1 + 2) were found beginning at 120 DD_{10} and their numbers peaked at 200 DD_{10}. Late larvae (instars 3 + 4) were present beginning at 160 DD_{10} and their numbers peaked at 350 DD_{10}. New generation adults appeared after 500 DD_{10}. In southern Alberta, alfalfa seed production is frequently combined with honey production. This algorithm enables producers to forecast the occurrence of the most damaging stage of alfalfa weevils which may require control with insecticides; the advance notice enables optimal timing of treatment and also allows apiarists to minimize pesticide mortality by moving or confining their bees.

Key words: Thermal units, degree days, simulation, phenology

INTRODUCTION

Pest control measures are economically justifiable only if their benefits exceed their cost (Stern *et al.* 1959). Normally, cost is the sum of pesticide purchase plus its application, and benefit is measured by reduced yield loss. However, other factors may enter the cost:benefit equation; this occurs in alfalfa production in southern Alberta, where seed producers frequently obtain additional income by charging apiarists to place honeybees (*Apis mellifera* L. (Hymenoptera: Apidae)) in their fields. Thus, strategies to control pest insects in alfalfa seed fields must acknowledge the susceptibility of honeybees to many pesticides.

One approach to reconciling alfalfa pest management with apiculture is to give apiarists sufficient warning to cover the hives, or to move them, before pesticides are applied. This approach requires a method of forecasting the occurrence of the pest population. This paper presents a simple method of doing so, which is based on observed correlations between phenological events and degree-day accumulations.

In southern Alberta, the alfalfa weevil is a serious insect pest of alfalfa, feeding on shoots, flower buds and foliage during prebloom to early bloom (Hamlin *et al.* 1949). If not controlled it can severely reduce seed yield. Adult alfalfa weevils spend the winter in protected locations in alfalfa fields or in litter nearby. Overwintered adults become active about the time the first alfalfa shoots appear in the spring. They feed for a few days, mate, and begin ovipositing. Peak egg density usually occurs in late May or early June, but eggs can be found during most of the summer.

Rates of pre-imaginal development are temperature-dependent. Egg incubation takes 4 to 21 days. Larvae develop through the four instars in about 3 to 4 weeks. Instars 1 and 2 (early larvae) feed within the tightly-curled developing leaves and buds; instars 3 and 4 (late larvae) feed on expanded leaves.

Feeding damage is most obvious in mid- to late-June, concurrent with peak densities of late larvae. Defoliation is most severe toward the terminals. This type of feeding results in loss of foliage, flower buds, and nutrients, with consequent delays in plant growth and development. Quantity and quality of the seed yield may be reduced.

Late larvae inflict the greatest damage, so agricultural losses can be expected to start accumulating at the onset of this life stage (Dennis *et al.* 1986). Consequently, the timing of control tactics for the alfalfa weevil should be optimized, based on an understanding of physiological

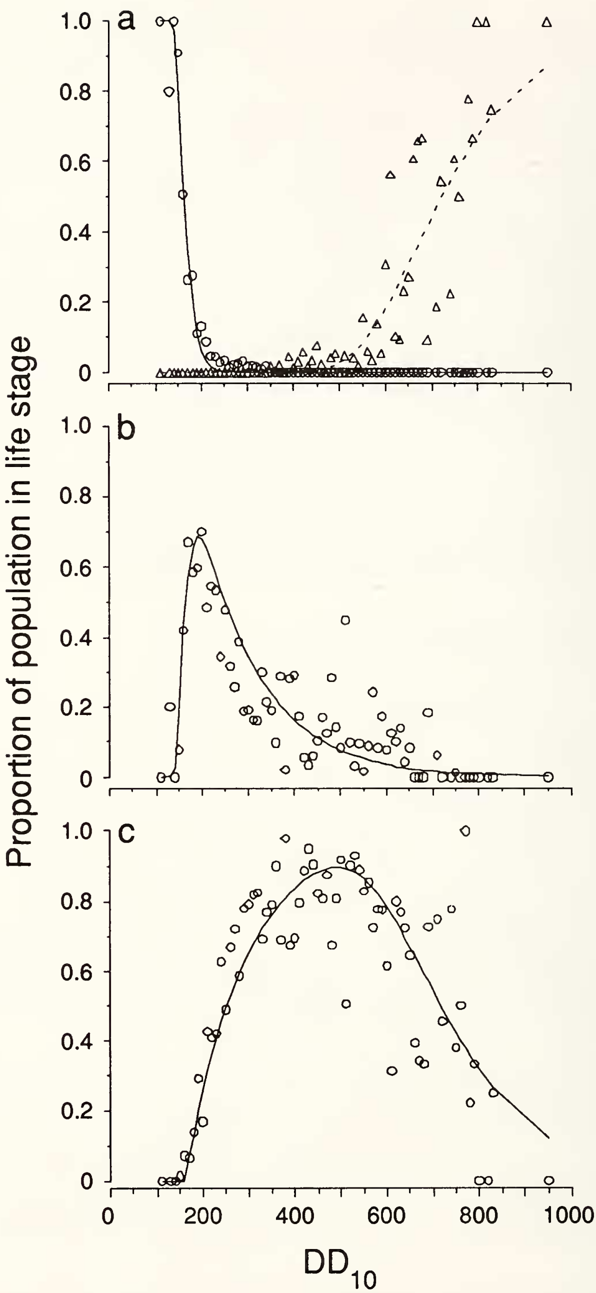

Figure 1. Observed and predicted proportion of alfalfa weevil in relation to DD_{10}. a) Overwintering adults (life stage = 1): o and solid line. New generation adults (life stage = 4) Δ and dotted line; b) first and second instars (early larvae; life stage = 2); c) third and fourth instars (late larvae; life stage = 3). Lines are predictions made using Equations 1-3 in text.

and behavioral processes (Harcourt 1981; Whitford and Quisenberry 1990), to target this life stage. This optimization requires information on the seasonal abundance and time of occurrence of the immature stages of the alfalfa weevil through a combination of population monitoring and phenological models (Schaber and Richards 1979).

In southern Alberta, chemical insecticides are the primary method of alfalfa weevil control. Efficient use of insecticides requires that applications should be timed to target the first late larvae, i.e. after they have moved to exposed positions on the leaves, but before they have caused much damage. This timing requirement establishes a potential conflict between pest control and honey production. A reliable method of forecasting the occurrence of late larvae could resolve this conflict.

This study was conducted to develop a technique that would predict the appearance of late instar alfalfa weevil larvae in seed alfalfa fields, using southern Alberta field data. This technique would enable better timing of insecticide applications in relation to insect development, and allow seed producers and apiarists more lead time to protect pollinators.

The temperature-dependence of insect development dictates that developmental models be based on thermal-unit accumulation. Simple methods for modelling phenology based on field data are available, and can be used to develop realistic models in the absence of detailed data on insect development processes (Hudes and Shoemaker 1988; Kemp and Onsager 1986; Kemp *et al.* 1986; Lysyk 1989). Degree-day accumulation has been used to predict peak hatch and subsequent activity of alfalfa weevil in forage alfalfa in southern Ontario (Harcourt 1981). However, Tauber *et al.* (1988) have suggested that the phenology of an insect species can vary among geographic regions due to adaptation of thermal biology to local climatic conditions, so another objective was to compare phenology of the alfalfa weevil populations in southern Ontario and southern Alberta.

METHODS

Algorithm development

The algorithm was developed using phenology data obtained from four research plots at the Agriculture and Agri-Food Canada Research Centre (AACRC) at Lethbridge, Alberta. Alfalfa weevil abundance was determined by taking five sweeps per plot with a 38-cm net (Johansen *et al.* 1979). Each plot was sampled every one to three days from 3 June to 12 August 1985; 12 May to 8 August 1987; 3 June to 20 July 1988; 3 June to 4 July 1989, and was sampled weekly from 4 June to 23 July 1990. Daily maximum and minimum temperatures (°C) were obtained from the AACRC meteorological station.

Alfalfa weevil phenology was modeled by correlating phenological events with degree-day accumulations using a developmental threshold of 10°C. This threshold was used because, although alfalfa weevil eggs hatch at 8°C, the resulting larvae do not survive even if subsequently exposed to a higher temperature (Guppy and Mukerji, 1974). Accumulated degree-days above 10°C (DD_{10}) from 1 January were calculated for each year by sine-wave integration (Allen 1976). Accumulated DD_{10} on each date was rounded to the nearest 10, and samples from the 4 plots were grouped according to these rounded values. The proportion of alfalfa weevils which were adults, early larvae and late larvae were calculated for all such grouped samples, and these proportions were related to the rounded DD_{10} accumulations by non-linear regression (Proc NLIN, SAS Institute 1989) as outlined below.

To provide a standardized estimate of when the weevils and larvae were most abundant, and to establish correlations between phenological events and DD_{10} accumulations, their relative abundance was calculated for each plot on each day in each growing season by summing the number of weevils collected and dividing by the greatest number collected in one day for that plot in that year. These relative abundances were grouped across plots and years by the rounded degree-day values. The correlations between relative abundance and DD_{10} accumulations were used to develop an algorithm to predict the appearance of the different life stages.

Alfalfa weevil phenology was divided into four stages (i): overwintered adults (i = 1), i.e.,

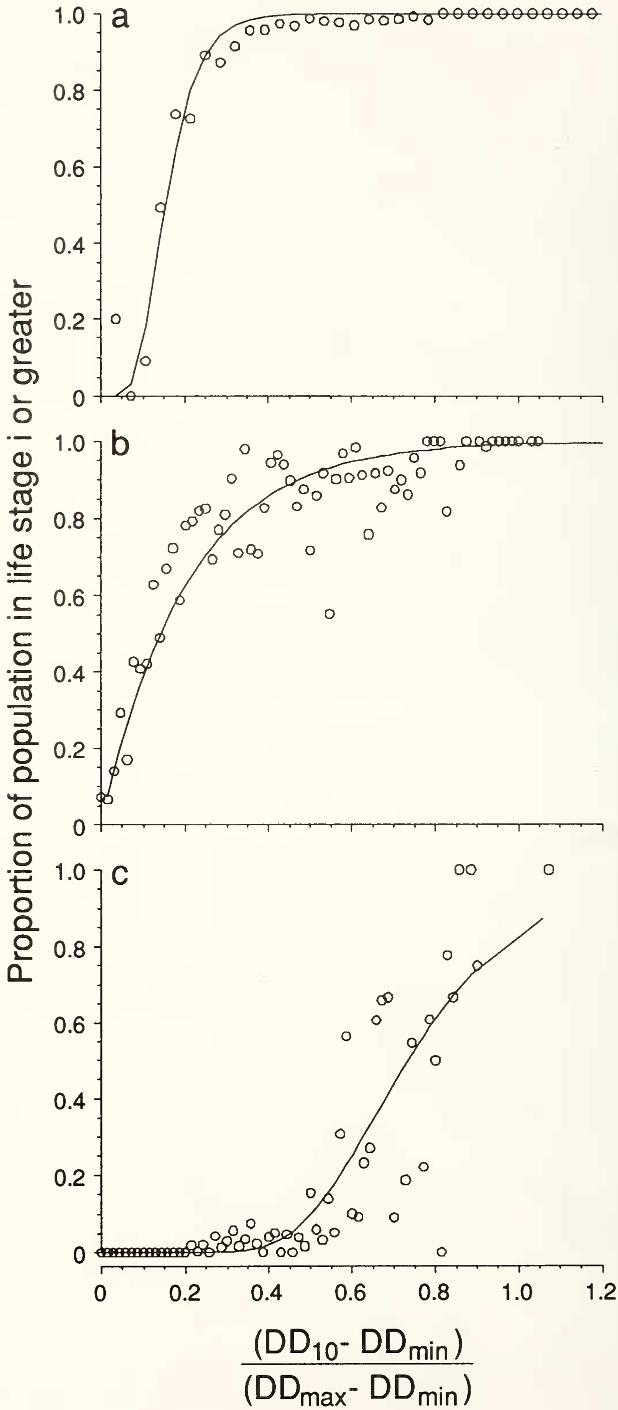

Figure 2. Proportion of alfalfa weevil in a) life stage 2 or greater, b) life stage 3 or greater, and c) life stage 4. Solid lines are model predictions using equation 2 and parameters estimates given in Table 1.

those present before the larval peak at 350 DD_{10}; early larvae (i = 2); late larvae (i = 3); and new generation adults (i = 4), i.e, those occurring after the larval peak at 350 DD_{10}.

The algorithm was developed as outlined below (Hudes and Shoemaker 1988). For each rounded DD_{10} value, the following calculations were made:

$$F_2 = (n_2 + n_3 + n_4) / \Sigma n$$
$$F_3 = (n_3 + n_4) / \Sigma n$$
$$F_4 = n_4 / \Sigma n$$

where n_i(i=2-4) is the number of weevils in life stage i, Σn is the total number of weevils, and F_i is the proportion of insects in life stage i or later. Note that because all insects are in a life stage equal or greater than the overwintered adult stage, $F_1 = 1$.

The time trends in each F_i were modelled using equation 1.

$$\hat{F}_i = [1 - e^{-a_i \cdot t_i}]^{b_i} \tag{1}$$

Non-linear regression was used to obtain estimates of the parameters (a_i, b_i; i = 2 - 4). The variable t_i is a scaled estimate of thermal time calculated for each life stage as:

$$t_i = \frac{DD_{10} - DD_{\min(i)}}{DD_{\max(i)} - DD_{\min(i)}} \tag{2}$$

In equation 2, $DD_{\min(i)}$ and $DD_{\max(i)}$ represent the approximate value of DD_{10} for the beginning and end of life stage i, obtained by inspection of the data.

The functions describing time-change in $_i$ were then used to predict the proportion of insects in each life stage ($\hat{p}_i$):

$$\begin{aligned} \hat{p}_1 &= 1 - F_2, \\ \hat{p}_2 &= F_2 - F_3, \\ \hat{p}_3 &= F_3 - F_4, \\ \hat{p}_4 &= F_4. \end{aligned} \tag{3}$$

Algorithm validation

Independently-obtained data were used to validate the algorithm. These were collected from plots in Brooks, Rosemary and Rolling Hills, Alberta (ca. 130 km N.E. of Lethbridge) by WestAg, Inc., a pest management scouting company. These plots were sampled weekly for up to 13 weeks in 1984-1988, starting the last week of May and continuing through August. Samples in a specific plot in each year were taken at approximately the same time of day to minimize any effects of insect diurnal cycle on sampling efficiency (Johansen *et al.* 1979). The data consisted of weekly mean numbers of adults and of early and late larvae. The numbers of fields sampled were 48, 40, 42, 48 and 42 for 1984 through 1988. Sample counts were tabulated weekly. Daily maximum and minimum temperatures were obtained for each year from the Alberta Special Crops and Horticultural Research Center in Brooks, Alberta, and the DD_{10} accumulation from January 1 were calculated by sine-wave integration (Allen 1976). The DD_{10} accumulation in the middle of each week was matched with the weekly insect data. The average proportion of weevils in the adult, early larval, and late larval stages was calculated for each week and compared graphically to the algorithm predictions.

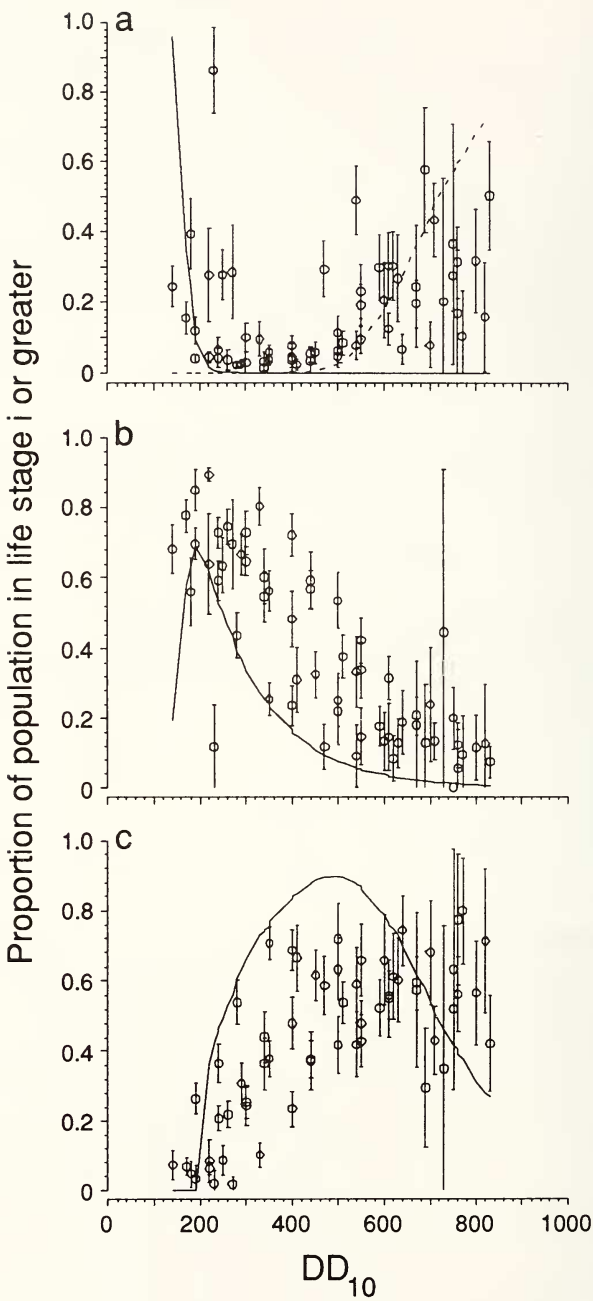

Figure 3. Proportion of alfalfa weevil in commercial seed alfalfa fields. Symbols are observed mean proportion ± 1 standard error, and lines are predictions made using Equations 1-3. a) adults, solid line is overwintered generation (life stage = 1) and dotted line is new generation (life stage = 4); b) first and second instars (early larvae; life stage = 2); c) third and fourth instars (late larvae; life stage = 3).

RESULTS

Seasonal phenology of alfalfa weevil

Adult weevils were first found at about 100 DD_{10} (Fig. 1a) and at that time were the only stage collected. The proportion of adult weevils declined from about 250 DD_{10} and they had become scarce by 350 DD_{10}. Early larvae appeared at about 120 DD_{10} (Fig. 1b), reached a maximum at about 200 DD_{10}, and then declined slowly. Late larvae appeared at ca. 160 DD_{10} (Fig. 1c), peaked near 450 DD_{10}, and then declined. New generation adult weevils began to appear after 400 DD_{10}, and increased steadily to nearly 100% of the population by 900 DD_{10}.

Algorithm output

Figure 1a-c illustrates the good agreeement between the algorithm output and the Lethbridge data. Estimates of the regression parameters are listed in Table 1. Coefficients of determination (r^2) were 0.97, 0.84, and 0.74 for life stages 2, 3 and 4 respectively. Model predictions of proportions of insects in life stage i or greater are overlaid with observations in Fig. 2a-c

Algorithm validation

Observed and predicted values of the proportion of weevils in each life stage for the test data are shown in Fig. 3 a-c. The predicted proportions of weevils in the adult life stages (1 and 4) seem reasonable (Fig. 3a). For early larvae, the algorithm predicted the timing of the peak population (Fig. 3b), and in general captured the seasonal population trends, but overall underestimated the proportion of weevils in this life stage. For late larvae (Fig. 3c) the algorithm predicted the start of the stage and captured the essence of the seasonal trends, but tended to overestimate the proportion of insects in this stage.

DISCUSSION

The phenology we observed differed from that recorded in Ontario (Harcourt 1981). In Ontario, most of the feeding damage occurred between 260 and 335 Degree-days base 9°C, whereas in this study, the damaging stage extended beyond 500 DD_{10}. These differences may reflect adaptation of the insect to a different cropping pattern, i.e. seed alfalfa *vs* forage alfalfa, or to a different climate. Harcourt's (1981) model does not seem to apply to the Alberta population of alfalfa weevil.

Table 1

Estimated parameters for component equations of the algorithm simulating alfalfa weevil population phenology.

	Equation (1)[a]			Equation (2)[b]	
Life Stage (i)	a	b	r^2	DDmin	DDmax
2	18.15	11.01	0.97	120	400
3	4.84	1.00	0.84	160	800
4	5.05	29.81	0.74	200	900

a Nonlinear regressions of the temporal change in proportions of observed insects in life stage (i), using

$$\hat{F}_i = [1 - e^{-a_i \cdot t_i}]^{b_i}$$

b Scaled estimates of thermal time for life stage (i), calculated as:

$$t_i = \frac{DD_{10(i)} - DD_{\min(i)}}{DD_{\max(i)} - DD_{\min(i)}}$$

Details are given in the text.

Although qualitatively similar, there is some discrepancy between the predictions and the validation data. Several factors can affect the accuracy and reliability of the algorithm. First, separating alfalfa weevil larvae into life stages is somewhat subjective, particularly when differentiating between second and third instars, and variation among observers can affect the accuracy of sampling for pest insect populations (Shufran and Raney 1989).

Another possible source of the discrepancies results from the differing ways in which samples were handled. The alfalfa weevils and larvae captured in the sweep net at Lethbridge were placed in paper bags and stored at −40°C until counted, whereas in the validation data they were counted in the field immediately after capture. These differences in method, coupled with the subjective assignment to stages, could affect the performance of algorithm.

Another possibility is that the use of degree-days may not be strictly applicable because it disregards both the nonlinearity of the developmental rate function (e.g. Lactin and Holliday 1993), and the ability of insects to control body temperature behaviourally (Huey and Kingsolver 1989), and can not account for the effects of transient unfavourable conditions (Lactin 1992).

Finally, insecticides were used in the commercial fields surveyed by WestAg, Inc., and differential mortality among the life stages may acount for the bias between algorithm predictions and field data. Early larvae feed mostly within the flower buds and are largely protected from contact insecticides, whereas late larvae feed on expanded foliage and are not (Johansen *et al.* 1979). These differences in exposure risk could bias the population structure of the validation fields, compared to that predicted by the algorithm, which was based on observations from insecticide-free fields.

CONCLUSION

This paper outlines the development of an algorithm to predict the occurrence of damaging stages of the alfalfa weevil. Although there is a consistent bias in the estimate of proportion of these stages in the population, the algorithm estimates the timing of stages quite well, and can provide sufficient advance warning to optimize the timing of insecticide application, and thus allow apiarists to remove or confine their bees.

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